BioSentinel

Active Technology Project (2013 - 2023)

Project Introduction

The Advanced Exploration Systems' (AES) BioSentinel project will develop, prototype, integrate, test, and prepare for the first spaceflight mission of a broadly applicable small satellite-based instrument platform to autonomously perform a range of human-exploration-relevant life-science studies of biological consequences of the space environment beyond Low Earth Orbit (LEO). The small, autonomous, low-power payload (a 6 unit CubeSat) will support biological/radiation testing on uncrewed missions such as Space Launch System (SLS) Artemis I.

Radiation damage studies will be conducted using the yeast *Saccharomyces cerevisiae* and will report DNA damage in response to ambient space radiation. The results will be critical for improving interpretation of the biological effects of space radiation exposure, and to reduce risk associated with long-duration human exploration.

The "6U" (10 x 22 x 34 cm; 12 kg) BioSentinel nanosatellite as a secondary payload to fly aboard NASA's first Space Launch System (SLS) Artemis I (previously referred to Exploration Mission (EM)-1). For the first time in over forty-five years, direct experimental data from biological studies beyond LEO will be obtained during BioSentinel's 6- to 12-month mission. BioSentinel will measure the damage and repair of DNA in a biological organism and allow us to compare that to information from onboard physical radiation sensors. In order to understand the relative contributions of the space environment's two dominant biological perturbations, reduced gravity and ionizing radiation, results from deep space will be directly compared to data obtained in LEO (on ISS) and on Earth. These data points will be available for validation of existing biological radiation damage and repair models, and for extrapolation to humans, to assist in mitigating risks during future long-term exploration missions beyond LEO.

The BioSentinel experiment will utilize the monocellular eukaryotic organism Saccharomyces cerevisiae (yeast) to report DNA double-strand-break (DSB) events that result from ambient space radiation. DSB repair exhibits striking conservation of repair proteins from yeast to humans. Yeast was selected because of 1) its similarity to cells in higher organisms, 2) the well-established history of strains engineered to measure DSB repair, 3) its spaceflight heritage, and 4) the wealth of available ground and flight reference data. The S. cerevisiae flight strain will include engineered genetic defects to prevent growth and division until a radiation-induced DSB activates the yeast's DNA repair mechanisms. The triggered culture growth and metabolic activity directly indicate a DSB and its successful repair. The yeast will be carried in the dry state within the 1-atm P/L container in multiple independent culture microwells, built into 96-well microfluidic plates with integral microchannels and filters to supply nutrients and reagents, confine the yeast to the wells, and enable optical measurement. The measurement subsystem will monitor each subgroup of culture wells continuously for several weeks, optically

BioSentinel spacecraft leaves Earth to a lunar fly-by trajectory and into a heliocentric orbit.

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tracking DSB-triggered cell growth and metabolism. BioSentinel will also include a physical radiation sensors based on the TimePix sensor, as implemented by JSC's RadWorks group, which record individual radiation events including estimates of their linear-energy-transfer (LET) values. Radiation-dose and LET data will be compared directly to the rate of DSB-and-repair events measured by the S. cerevisiae biosentinels.

The spacecraft bus will occupy ~2U, including command and data handling, communications, power generation (via deployable solar panels) and storage, and attitude determination-and-control system with micropropulsion. Development of the BioSentinel spacecraft will mature and prove multiple nanosatellite advances in order to function well beyond LEO:

- Communications from distances of ≥ 500,000 km
- Autonomous attitude control and momentum management of nanosatellites in deep space
- Shielding-, hardening-, design-, and software-derived radiation tolerance for electronics
- Reliable functionality for 12 months of key subsystems for biofluidics, memory, communications, power, etc.
- Close integration of living biological radiation event monitors with miniature physical radiation spectrometers
- Biological measurement of solar particle events beyond Earth orbit

In addition to providing the first biological results from beyond LEO in over 4 decades, BioSentinel will provide an adaptable small-satellite instrument platform to perform a range of human-exploration-relevant measurements that characterize the biological consequences of multiple outer space environments. BioSentinel is being developed under NASA's Advanced Exploration Systems program.

BioSentinel technology will provide critical information about how living systems, from humans down to cells, adapt, respond and survive in deep space, beyond LEO, furthering our understanding of radiation effects on biological systems and the potential countermeasures needed to enable future deep-space exploration missions. Using autonomous 6U CubeSats is an innovative, low-cost, low-risk, high pay-off approach to conduct research and technology investigations.

DSB repair exhibits striking conservation of repair proteins from yeast to humans. The BioSentinel project uses yeast not only because of its similarity to cells in higher organisms, but also because of 1) the well-established history of strains engineered to measure DSB repair, 2) yeast's flight heritage, and 3) the wealth of available ground- and flight-reference data.

Organizational Responsibility

Responsible Mission Directorate:

Exploration Systems Development Mission Directorate (ESDMD)

Lead Center / Facility:

Ames Research Center (ARC)

Responsible Program:

Exploration Capabilities

Project Management

Program Director:

Christopher L Moore

Project Manager:

Matthew C Napoli

Principal Investigator:

Sergio R Santa Maria

Co-Investigators:

Lauren C Liddell
Diana M Gentry

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One S. cerevisiae flight strain will contain engineered genetic defects to prevent growth and division until a radiation-induced DSB near (~1000 bases) the target genes activates the yeast's DNA repair mechanisms: culture growth and metabolic activity will indicate directly a DSB and its successful repair. In parallel, a different yeast strain that cannot repair DSBs will provide survival curves: increased space radiation-induced DSBs cause decreased cell survival. Each of the multiple yeast strains is carried in multiple independent culture wells, subgroups of which are activated at multiple time points over a 6 – 12-month mission. The instrument monitors each subgroup of 12 culture wells continuously for 4 weeks, tracking cell growth via optical density and metabolic activity using a viability dye: growth indicates DNA damage and repair. A payload containment designed for minimal shielding of the cells provides biologically significant radiation doses in orbits beyond LEO. Far higher doses can be expected during a solar particle event (SPE), triggering additional measurements by our biosensors. The DSB rate in space will be compared to (a) physically measured radiation dose, (b) studies conducted in terrestrial radiation facilities, and (c) models of expected DNA damage-and-repair rates. Due to the unique composition, flux, and energy distribution of space radiation, it is expected that the radiation-induced responses in space will differ from ground-based data.

The results will be critical for improving interpretation of the biological effects of space radiation exposure, and to reduce risk associated with long-duration human exploration.

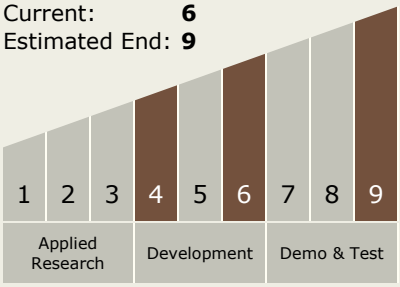
Anticipated Benefits

The BioSentinel project will provide:

- A radiation biosensor capability that will be utilized in future robotic and human missions to the Moon, Near Earth Asteroids (NEAs), and Mars, for evaluation of the long-term biological effects of deep--space radiation. The biosensor is adaptable for space platforms including the Gateway & Lunar Landers.
- A capability to carry out microbial research on a miniaturized platform for various robotic and human missions.
- In-situ analysis and data collection
- Develop the accommodations, interfaces, and integration for Secondary Payloads on Space Launch System (SLS) Artemis I, that pave the way for more Secondary Payloads on future SLS launches.

Technology Maturity (TRL)

Start: **4**
Current: **6**
Estimated End: **9**



Technology Areas

Primary:

- TX06 Human Health, Life Support, and Habitation Systems
  - TX06.3 Human Health and Performance
    - TX06.3.6 Long Duration Health

Target Destination

Others Inside the Solar System

Supported Mission Type

Planned Mission (Pull)

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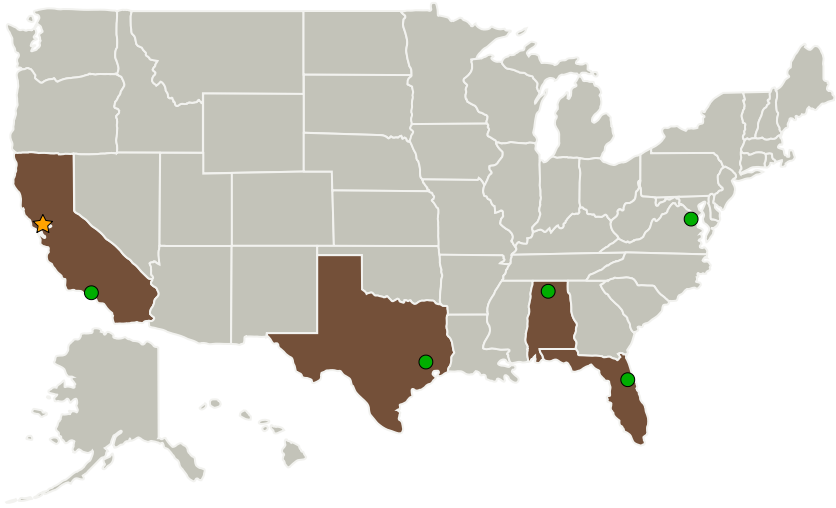
Primary U.S. Work Locations and Key Partners



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Organizations Performing Work	Role	Type	Location
★Ames Research Center(ARC)	Lead Organization	NASA Center	Moffett Field, California
●Jet Propulsion Laboratory(JPL)	Supporting Organization	NASA Center	Pasadena, California
●Johnson Space Center(JSC)	Supporting Organization	NASA Center	Houston, Texas
●Kennedy Space Center(KSC)	Supporting Organization	NASA Center	Kennedy Space Center, Florida
Loma Linda University Medical College	Supporting Organization	Academia	Loma Linda, California
●Marshall Space Flight Center(MSFC)	Supporting Organization	NASA Center	Huntsville, Alabama
●NASA Headquarters(HQ)	Supporting Organization	NASA Center	Washington, District of Columbia
University of Saskatchewan	Supporting Organization	Academia	Saskatoon, Outside the United States, Canada

Primary U.S. Work Locations	
Alabama	California
District of Columbia	Florida
Texas	

Images

Illustration of BioSentinel flying over Earth

BioSentinel spacecraft leaves Earth to a lunar fly-by trajectory and into a heliocentric orbit.
(https://techport.nasa.gov/image/143259)